The mean percentage of CP2 stars in the Milky Way is of the order of 5% for the spectral range from early B- to F-type, luminosity class V objects. The origin of the CP2 phenomenon seems to be closely connected to the overall metallicity and global magnetic field environment. The theoretical models are still only tested by observations in the Milky Way. It is therefore essential to provide high quality observations in rather different global environments. The young clusters NGC 2136/7 were observed in the Δa photometric system. This intermediate band photometric system samples the depth of the 520 nm flux depression by comparing the flux at the center with the adjacent regions with bandwidths of 11 nm to 23 nm. The Δa photometric system is most suitable for detecting CP2 stars with high efficiency, but is also capable of detecting a small percentage of non-magnetic CP objects. Furthermore, the groups of (metal-weak) λ Bootis, as well as classical Be/shell stars, can be successfully investigated. We present high precision photometric Δa observations of 417 objects in NGC 2136/7 and its surrounding field, of which five turned out to be bona fide magnetic CP stars. In addition, we discovered two Be/Ae stars. From our investigations of NGC 1711, NGC 1866, NGC 2136/7, their surroundings, and one independent field of the LMC population, we derive an occurrence of classical chemically peculiar stars of 2.2(6)% in the LMC, which is only half the value found in the Milky Way. The mass and age distribution of the photometrically detected CP stars is not different from that of similar objects in galactic open clusters.

Key words. Stars: chemically peculiar – stars: early-type – techniques: photometric – Magellanic Clouds – open clusters and associations: individual: NGC 2136

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Chemically peculiar stars in the Large Magellanic Cloud*

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Abstract. The detection of magnetic chemically peculiar (CP2) stars in open clusters of extragalactic systems can give observational answers to many unsolved questions. For example, one can study the influence of different global as well local environments on the lack of and presence of peculiarities.

1. Introduction

The classical chemically peculiar (CP) stars of the upper main sequence (luminosity classes V and IV) are targets of detailed investigations since their first description by Maury (1897). They provide excellent test objects for astrophysical processes like diffusion, convection, and stratification in stellar atmospheres in the presence of rather strong magnetic fields. These mechanisms for stars, both in the Milky Way and its surrounding stellar systems, contribute important knowledge to stellar evolution under different local circumstances, e.g., different metallicities.

CP stars can be detected very efficiently by applying the Δa photometric system (cf. Paunzen et al. 2005a), which measures the characteristic broadband absorption feature located around 520 nm, which is most certainly a consequence of the non-solar elemental abundance distribution of CP and related objects in the presence of a strong stellar magnetic field (Kupka et al. 2004). It samples its depth, comparing the flux at the center (521 nm, g_2), with the adjacent regions (503 nm, g_1 and 551 nm, y), using bandwidths from 11 nm to 23 nm. The respective index a was introduced as

$$a = g_2 - (g_1 + y)/2.$$

The intrinsic peculiarity index Δa is defined as the difference between the individual a-values and those ($= a_0$) of non-peculiar stars of the same color. The locus of the a_0-values has been called, the normality line.

Virtually all peculiar objects with magnetic fields (CP2 and CP4 stars, Preston 1974) have positive Δa values in excess of +100 mmag whereas Be/Ae/shell and metal-weak (e.g., λ Bootis group) stars exhibit significantly negative ones up to −35 mmag (Paunzen et al. 2005a). In general, some spectroscopic binary systems can mimic a positive Δa value of up to +16 mmag, which is well below the observed values for the stars presented in this paper. Later type, evolved objects of luminosity classes III to I might also show the same behavior, but can be easily identified within the color-magnitude diagram and do not influence the overall statistics.

In this paper we present our efforts to detect chemically peculiar stars in the field of NGC 2136/7, a binary cluster system, located in the Large Magellanic Cloud (LMC). In total, we observed 417 objects of which five turned out to be bona fide magnetic CP stars. These observations, added to our statistical analysis in the LMC presented in Paunzen et al. (2005b), show an overall occurrence of 2.2(6)% for chemically peculiar stars in the LMC.

2. Observations and reduction

The observations were done on twelve nights at two different telescopes with the identical Δa filter set:

– CASLEO: 215 cm telescope, TEK-1024 CCD, field of view of about 9.5′, August 2001 and January 2003, observer: O.I. Pintado

* Based on observations at CASLEO and ESO-La Silla
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Table 1. Peculiar objects found in the field of NGC2136/7 (upper part) and its surrounding area (lower part). The objects No. 127 and 228 are most certainly not classical chemically peculiar stars, whereas No. 219 is a red supergiant with high mass-loss and emission. The errors in the final digits of the corresponding quantity are in parenthesis.

No	X	Y	$(B-V)_0$	Δa	M_V
165	+47.79	−87.73	+0.164(7)	+0.095	−0.449(5)
204	+98.00	−16.22	−0.255(8)	−0.062	−1.480(6)
219	+110.54	−57.90	+0.479(14)	−0.056	−4.153(9)
228	+117.09	−30.35	+0.443(8)	+0.074	−4.264(6)
233	+120.22	−214.24	−0.220(2)	+0.044	−1.051(2)
283	+167.19	−96.05	−0.084(3)	+0.049	−1.663(2)
91	−91.72	−416.28	−0.205(7)	+0.041	−1.483(7)
110	−54.52	−157.76	+0.005(8)	+0.060	+0.051(7)
127	−13.32	−146.05	+0.701(10)	+0.053	+0.330(6)
392	+377.70	−202.34	+0.033(3)	−0.053	−0.709(2)

– ESO-LaSilla: Bochum 61 cm telescope, Thompson 7882 CCD, 384x576 pixels, $3' \times 4'$, April 1995, observers: H.M. Maitzen and E. Paunzen

The filters have the following characteristics: g_1 ($\lambda_c = 5027$Å, FWHM = 222Å, Peak transmission = 66%), g_2 (5205/107/50), and y (5509/120/54). In total, 69 frames for the three filters (20/23/26) were obtained.

The bias subtraction, dark correction, flat-fielding, and a point-spread function fitting were carried out within standard IRAF V2.12.2 routines on a Personal Computer with a Linux distribution.

One of the advantages of the Δa photometric system is that the "standard" as well as program stars are always on the same frame. Because of instrumentally induced offsets and different air masses between the individual frames, photometric reduction of each frame was performed separately and the measurements were then averaged and weighted by their individual photometric errors.

In total, 417 stars were measured in the field. We were not able to resolve the innermost regions ($\approx 20''$) of NGC2136/7 due to the seeing conditions and saturation.

The tables with all data for the individual cluster stars as well as nonmembers are available in electronic form at the CDS via anonymous ftp to cdsarc.u-strasbg.fr (130.79.128.5), http://cdsweb.u-strasbg.fr/Abstract.html, or upon request from the first author. These tables include our internal numbers, J2000.0 coordinates, the X and Y coordinates within our frames, the observed (g_1-y) and a values with their corresponding errors, the V magnitudes, the $(B-V)$ colors from the literature, the Δa-values derived from the normality lines of (g_1-y) (excluding nonmembers), and the number of observations, respectively.

3. NGC 2136/7 and its surrounding field population

Dirsch et al. (2000) concluded that NGC 2136 and NGC 2137 are a physical binary (possibly triple) cluster system of same age ($\log t = 8.0$) and metallicity ([Fe/H] = −0.55) located at $\alpha(2000.0) = 05^{\rm h}53^{\rm m}00^{\rm s}$ and $\delta(2000.0) = -69°29'30''$. The estimated reddening of $E(B-V) = 0.1$ mag is typical for other clusters in the LMC.

Especially interesting is their result of the surrounding field population. They found a younger age and lower metallicity than for the clusters. However, the error of their metallicity determination is 0.59 dex.

Unfortunately it was not possible to use the Strömgren photometry from Dirsch et al. (2000) for the calibration of our photometric values and the identification of objects because it has been available neither in electronic form nor upon request from the authors of the given reference. Furthermore, no printed tables are available.

We have therefore used the Johnson-Kron-Cousins photometric $UBVI$ data published by Zaritsky et al. (2004). They provide no consecutive numbering system but equatorial coordinates (see their Table 1). The identification of stars in common was done in two steps. First of all, we identified the brightest objects by eye and derived a first calibration of the instrumental magnitude y_{inst} versus V and the coordinates within our frames (X, Y) versus (α, δ). With these preliminary values, a second automatic iteration was done limiting the magnitude difference to 0.5 mag and a varying radius limit. It is difficult to decide which objects coincide in the cluster areas of NGC 2136/7. If more than one object from the catalogue by Zaritsky et al. (2004) matches at the same level of significance, we did not include its $UBVI$ data in the analysis. In total we identified 248 objects that were used for the final calibration of the instrumental magnitudes y_{inst} and $(g_1-y)_{inst}$. In parenthesis are the errors in the final digits of the corresponding quantity

$$V = -5.372(15) + 0.983(5) \cdot y_{inst} \quad (1)$$

$$B-V = +3.12(6) + 2.38(6) \cdot (g_1-y)_{inst}. \quad (2)$$

The absolute magnitudes were calculated by using the distance modulus of 18.5 mag taken from Alves (2004) and $A_V = 3.1 \cdot E(B-V) = 0.31$ mag.

150 apparent members of NGC 2136/7 were selected based on the cluster radii and coordinates listed in Dirsch et al. (2000).

For the normality line, the (g_1-y) measurements were converted into dereddened $(B-V)_0$ values. The normality lines of NGC2136/7 and its surrounding area coincide excellently, allowing to merge them into one final diagram. The following correlation for the normality line was found to be

$$a_0 = 0.540(1) + 0.113(1) \cdot (B-V)_0. \quad (3)$$

The result is shown graphically in Fig. 1. The 3σ limit is estimated to be ±0.014 mag, a value which is well in line with those of galactic open clusters, taking into account the magnitude limit of about $V = 19$ mag that was reached (Paunzen et al. 2005c).

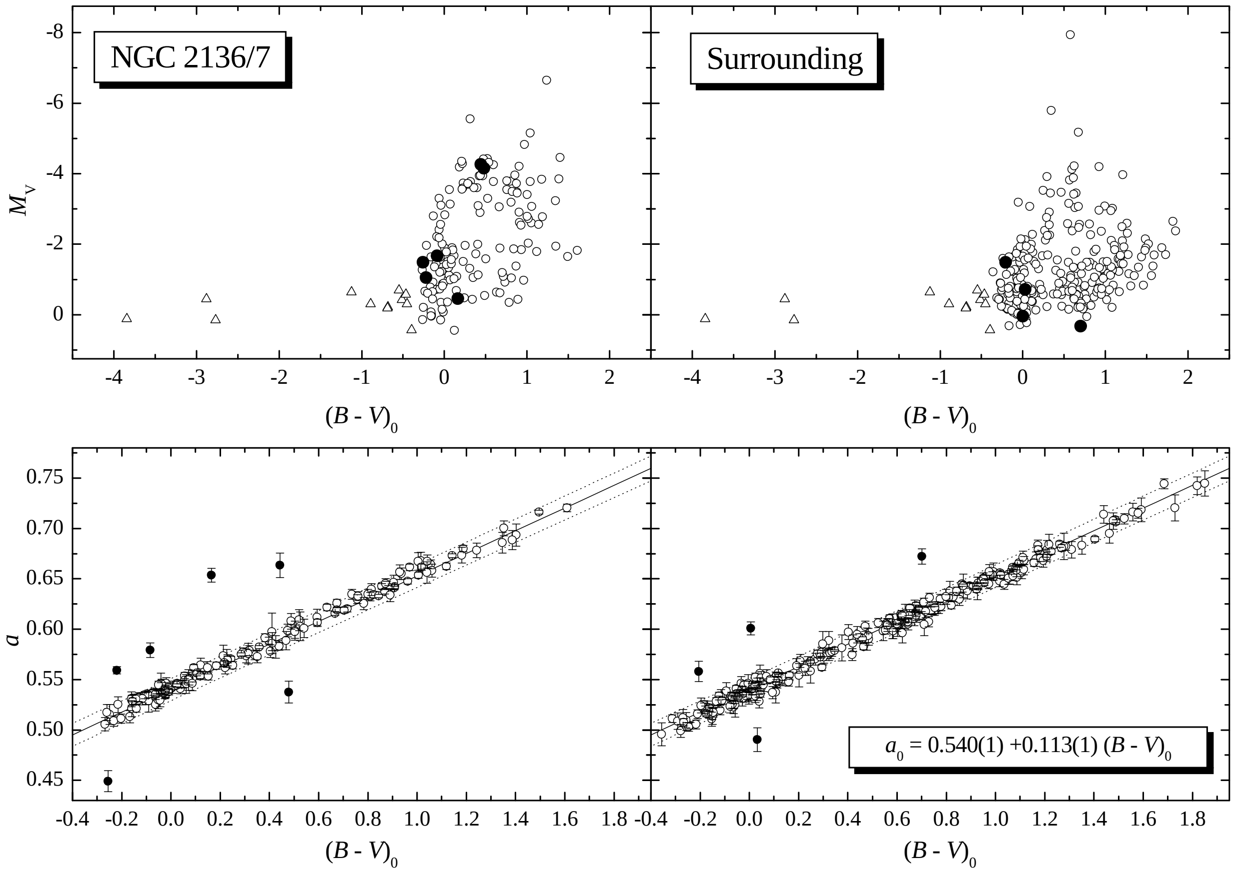

Fig. 1. Observed diagrams for NGC2136/7 (left panels) and its surrounding area (right panels). The solid line is the normality line whereas the dotted lines are the confidence intervals corresponding to 99.9%. The open circles are members and the filled circles are peculiar stars, whereas the triangles are non-members. The error bars for each individual object are the mean errors. The measurement errors of M_V are much smaller than the symbols and have been omitted. The M_V and $(B-V)_0$ values were calculated using a distance modulus of 18.5 mag and a reddening $E(B-V) = 0.1$ mag.

4. Results

In Table 1, we have summarized the results for the peculiar objects that deviate significantly from the normality line (Fig. 1).

From the photometric indices we conclude that the objects No. 91, 110, 165, 233, and 283 fall well into the domain of the classical magnetic chemically peculiar objects (Gómez et al. 1998).

The star No. 228 is a red supergiant with $(B - V)_0 = +0.443(8)$ and $M_V = -4.264(6)$ mag. This star group can exhibit positive Δa values as investigated by Paunzen et al. (2005a). Also, No. 219 turns out to be a red supergiant, but with the opposite effect of having a significant negative Δa value probably caused by a high mass-loss rate together with emission in the stellar envelope (van Loon et al. 1999). This might be an effect bearing some similarity to Be stars (Pavlovski & Maitzen 1989).

Object No. 127 cannot be addressed as a classical chemically peculiar star. Its $(B - V)_0$ value of $+0.701(10)$ mag and absolute magnitude of $+0.330(6)$ mag is typical of an evolved G-type star of luminosity class IV to III (Ginestet et al. 2000). The evolutionary status of it is not in line with the age of NGC 2136/7, but it would be compatible with the ages derived for the field population of the LMC (Dolphin 2000). There are several peculiar, mainly CN and CH abnormal stars, in this spectral domain (Taylor 1999). The capability to detect such objects with Δa photometry has not yet been investigated and certainly deserves further research.

Finally, No. 204 and 392, which show significant negative Δa values, are probable Be/Ae stars because they seem to be too hot for members of the λ Bootis group (Paunzen et al. 2002).

We follow the approach given by Paunzen et al. (2005b) and derive the total number of chemically peculiar stars having significant positive Δa values in NGC 2136/7 and its surrounding field compared to all investigated objects in the relevant spectral range up to F2 or $(B-V)_0 = 0.3$ mag resulting in 2.7% and 1.8%, respectively. Using these values and those listed in Table 3 of Paunzen et al. (2005b), we derive a mean occurrence of 2.2(6)% for chemically peculiar stars in the LMC.

North (1993) studied the percentage of chemically peculiar stars in open clusters of the Milky Way. He found a number of 5% to 10% for the magnetic ones in open clusters with similar ages to those used for this study (see his Figure III). This percentage is almost identical with that of the galactic field. The number for the LMC is only about half the value that in the Milky Way. Up to now, no correlation of this mean value with the metallicity and the occurrence in clusters or the field population of the LMC is evident.

This result is based on four widely different fields in the LMC, making it highly significant, which is important for theories of the origin and evolution of CP stars. The overall metallicity of the LMC is reduced by up to 0.5 dex compared to the Sun, and its global magnetic field consists of a coherent axisymmetric spiral of field strength that is weaker than that of the Milky Way. Both parameters might significantly influence the origin of the CP stars' magnetic fields. Still it is a matter of debate if the stellar magnetic field is due to the survival of frozen-in fossil fields originating from the medium out of which the stars were formed or if a dynamo mechanism is acting in the stellar interior.

As a last step, we have calibrated the masses and ages for all 35 photometrically detected CP stars in the LMC using appropriates isochrones by Claret (2006). They take into account the reduced metallicity and moderate core overshooting ([X] = 0.739, [Z] = 0.007, $a_{ov} = 0.20$). All stars were individually fitted to derive the age and mass with a distance modulus of 18.5 mag as well as a reddening of $E(B-V) = 0.1$ mag. Such a "statistical" approach naturally introduces an unknown error for the determination of the masses and ages for the individual objects. But, none of the investigated clusters significantly deviates from the chosen values (Maitzen et al. 2001; Paunzen et al. 2005b). From our experience (Claret et al. 2003; Pöhnl et al. 2005), we estimate a heuristic error of about 15% for the individual parameters. However, we will only analyze the complete sample of CP stars and not specific objects. Figure 2 shows the histograms of the ages and masses of the investigated sample of 35 photometrically detected CP stars excluding probable cool type objects and Be/Ae as well as metal-weak stars. One has to keep in mind that this sample is biased due to poor number statistics and the census of the investigated spectral range (= masses).

The Δa values are at a maximum around A0 for CP2 stars and decrease for hotter and cooler objects, which reflects the incidence of these objects in respect to all stars in this spectral range (Maitzen & Vogt 1983). The occurrence of hot CP4 stars compensates, to a certain amount, the overall percentage for early to late B-type objects (Paunzen et al. 2005a). This behavior can be also seen in Fig. 2.

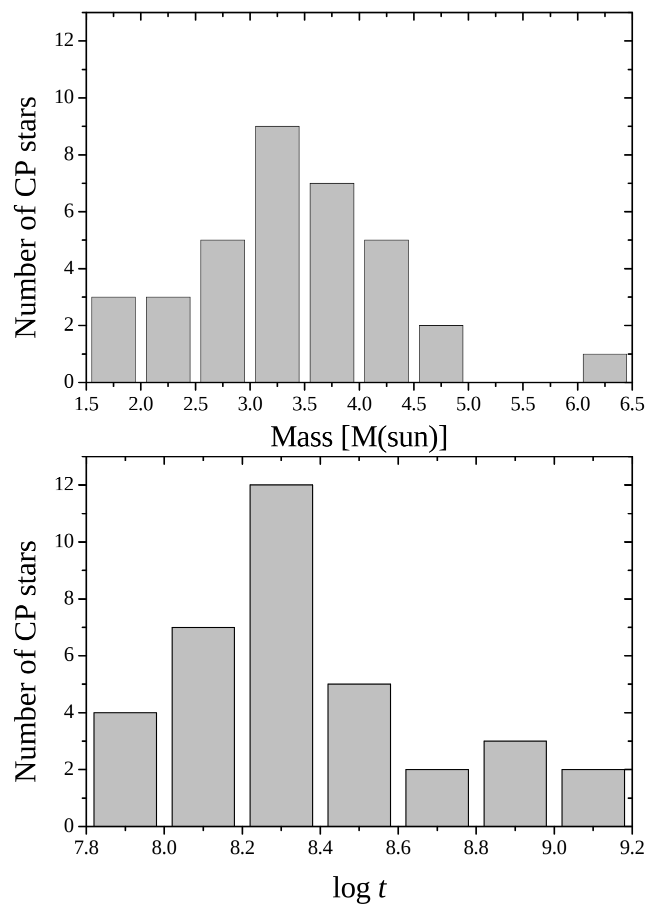

Fig. 2. Mass (upper panel) and age (lower panel) distribution for all 35 photometrically detected CP stars in the LMC. The isochrones for the analysis are from Claret (2006) who takes the reduced metallicity of the LMC into account. The distributions are compatible with those of open cluster CP stars in the Milky Way (North 1993).

If we compare Fig. 2 to the results for CP stars in galactic open clusters by North (1993), we find perfect agreement for the following conclusion: *all kinds of CP stars are main sequence, core-hydrogen burning objects with masses between 1.5 and 7* $M_{\odot}$.

5. Conclusions

We present the results of our search for CP stars of the upper main sequence in the LMC clusters NGC2136/7 and the surrounding field applying the intermediate band Δa photometry, which measures the characteristic broadband absorption feature located around 520 nm.

In total, 417 objects were measured on 69 individual frames observed with two different telescopes. We report the detection of five classical chemically peculiar objects and two Be/Ae stars. In addition, three peculiar objects were found that deserve further attention.

We conclude from our investigations of NGC 1711, NGC 1866, NGC 2136/7, their surroundings, and one independent field of the LMC population that the occurrence of classical chemically peculiar stars is 2.2(6)% for chemically peculiar stars in the LMC.

The age and mass distributions, derived by applying appropriate isochrones, do not alter from those of CP stars in galactic open clusters.

This provides a valuable observational source for understanding the CP phenomenon of the upper main sequence in a different global environment than in our Milky Way.

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